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(57) Abstract

A multi-beam array optics system useful as a pattern generator for electron beam lithography includes a field emitter array of micro-cathodes formed on a substrate for emitting an electron multi-beam array, an extracting electrode array on the substrate for controlling the emission of the field emitter array, a deflecting array on the substrate for deflecting the individual electron beams emitted by the micro-cathode to reduce beam shift, and electron optical elements that accelerate and direct the multi-beam array to a target as if it were a single unitary beam.

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MULTI-BEAM ARRAY ELECTRON OPTICS

FIELD OF THE INVENTION

This invention relates to multi-beam array charged particle optics and related systems, and particularly to a pattern generator using a multi-beam array.

BACKGROUND

It is well known in the field of electron beam pattern generation that it is desirable to increase the throughput of pattern generation systems. The two main applications for such pattern generation systems are making masks for use in semiconductor fabrication by photolithography and direct writing of patterns onto wafers to form semiconductor devices. The need to individually scan an electron beam or ion beam pattern onto a substrate, i.e. a mask or a wafer, is a relatively slow process. One attempt to improve the throughput in for instance electron beam pattern generators is described in "A Concept for a 10 GHz Pixel Rate (Multiple) E-Beam Machine" by D.J.G.M. Roelofs et al., Microcircuit Engineering 83, 1983, pp. 91 and following, which discloses use of a matrix of 32x32 focused electron beamlets which can be blanked individually. Each beamlet is individually focussed by a so-called fly's eye lens which is a composite composed of a number of small lenses, each small lens being associated with one of the beamlets.

This approach is deficient at least because each individual beamlet is susceptible to asymmetries of various kinds due to contamination present in the electron beam column, for instance due to particles lodged in apertures in the column. This contamination operates differentially on the various beamlets, resulting in the beamlets being displaced relative to one another, reducing the accuracy of the pattern being

written.

Also known is the microcolumn approach in which individual microcolumns, each for instance one centimeter in diameter, are arranged in a square array to provide a multiplicity of electron beams. This is complex and expensive due to the need to individually fabricate the microcolumns, each having its own deflector, accelerator, and focussing electron beam optics.

Further known is the array cathode approach, which achieves high density integration of electron beam sources in one and two dimensions. Due to dielectric breakdown, these devices are limited in the energy that may be imparted to the emerging electrons, and thus have limited utility for electron beam pattern generation.

Also known in the art is the use of negative electron affinity photocathodes illuminated by laser beam as multibeam sources of electrons. Schneider et al., J. Vac. Sci. Technol. B 14(6), 3782-3766, Nov/Dec 1996 propose such an electron beam system. Negative electron affinity materials such as cesiated GaAs are known to be extremely sensitive to contamination, which reduces or eliminates the emission of electrons. In the vacuum environment typically found in an electron beam pattern generator, one therefore expects limited lifetime for such a multibeam cathode.

Prior work in this field does not solve the problem of increasing throughput of charged particle beam systems while being commercially feasible. The main obstacles to commercialization of direct writing of semiconductor wafers are on the one hand the low throughput of conventional charged particle beam systems, and on the other hand the very limited beam energy, on the order of a few hundred volts, of parallel array beam sources. (See, for example,

MacDonald et al., Proceedings SPIE 2522 (1995) 220-229.) This limited beam energy forces the optical path length from emitter to target to be very short (approx. 1 mm) in order that there not be undue inter-beamlet distortions. Further, because of the low energy, the particles cannot penetrate conventionally thick resist materials (4000 Å) on the target. For this reason the resist is not exposed. Furthermore, alignment marks buried under such resist are not visible to the beams.

Hence to date commercial use of electron beam lithography has been limited to mask making. Even for mask making it is desirable to increase throughput using beams of conventional energy, as integrated circuits become more complex, requiring more complex masks.

SUMMARY

In accordance with this invention, a pattern generator and a method of generating patterns use a source of charged particles, the source being an array of individual source elements, formed in one embodiment on a single substrate, and each source element in the source emitting an individual charged particle beam. The charged particle beams then pass through a beam assemblage optics which receives the individual charged particle beams and controls and accelerates them as if they were a single beam. That is to say, in the beam assemblage optics there is no individual deflector or accelerator for each beam. Instead, the individual charged particle beams are treated as a single unitary beam, and then are accelerated and directed onto a target, for instance a semiconductor wafer or a reticle substrate held on a suitable support, as in conventional charged particle beam lithography.

Typically the beam assemblage optics includes at least one deflector which deflects substantially

uniformly the entire beam assemblage, a focus element which is a conventional "lens", and an accelerator element which accelerates the entire beam assemblage as if it were a single beam, i.e. does not independently accelerate the individual beams but accelerates all the beams uniformly. This pattern generator may operate in either a vector scan or raster scan mode.

Each individual element in the source is individually addressable in terms of being blanked and unblanked. In some embodiments instead of the individual source elements being blanked and unblanked, a group of elements (for instance a square subarray of source elements) is blanked and unblanked. The blanking and unblanking typically are accomplished by an individual source potential provided to each source element or by an individual extraction potential provided to each source element.

"Beam" here refers to an identifiable stream of charged particles. In accordance with common usage this disclosure uses the term "beam" independently of whether the beam itself is blanked (turned off) or turned on. Thus this defines a static beam axis which is the central path followed by the particles in the beam. "Beamlet" here refers specifically to an individual beam within the assemblage of beams in a multi-beam system.

Multi-beam here refers to multiple charged particle beams in a single grouping of beams. ("Multi-beam" as used here is not intended to refer here to a multi-column electron beam system as known in the art, where individual electron beams are each in its own column and each has its own optical arrangement.) The term "array" used herein refers to for instance (but is not limited to) a row and column array having whatever shape is desired i.e. square, rectangular, circular, or linear, disposed in one or two dimensions. Other array

geometries may be appropriate. The array need not lie in a plane but may be on some other regular surface such as the surface of a sphere or cylinder. The array of individual particle source elements is provided with extractors for extracting the particles from the source elements, thereby initiating the formation of a multiplicity of individual electron beams. This extraction can either be by a structure integrated with the array source itself as an array of individual extractors, or be a single extractor for all of the particle sources as a collective.

The array of source elements is provided with blanking and unblanking (turning off and turning on) structure which in one embodiment operates on each source element independently of each other source element. Alternatively the independence is not of individual source elements in some embodiments, but is an arbitrary collection or grouping of source elements, i.e. a subarray. For instance it may be desirable in a rectangular array to turn on or off an entire selected row or column of source elements independently of the other rows or columns, or to turn off small rectangular blocks of source elements. The blanking may be provided by independent control of the individual source element potential (voltages) or via the individual extraction potentials where individual extractors are provided, or a combination thereof.

In another embodiment, the source array includes not only an independent blanking structure but also independent "lenses" (one for each source element) for focussing the particle beams. ("Lens" and "optics" or "optical" here conventionally refer not to light optics or light refractive lenses but to electro-magnetic or electrostatic structures for focusing charged particle beams.) These lenses are fabricated as additional steps in the fabrication of the source structure. The

lenses are used for specific particle beam system applications, for example to match the source optics to the column optics for efficient beam transport. In one embodiment, independent deflectors are provided for the individual beams. Again these individual deflectors are fabricated as additional steps in the source structure fabrication process and are integrated therein. A selected beam deflector, when actuated, causes the direction of the particular electron beam emitted from the associated source element to be changed from one direction generally aligned with the particle beam system axis to a slightly different direction; typically the deflection is only within a few degrees of the overall beam axis but is greater in other embodiments.

The source array contemplated within the scope of this invention emits particles which are electrons or

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